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INVESTIGATION OF THE INFLUENCE OF TI-AL-B ON THE HIGH-TEMPERATURE PROPERTIES OF CR-NI-MO-FE AUSTENITIC ALLOYS

by

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To

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SUMMARY

This is the fourth quarterly progress report under Contract No. AF 33(616)-173. This report concludes the work done on six experimental alloys containing varying amounts of boron and titanium, the object of the work on these six modifications being to determine trends of physical properties and behavior characteristics with composition. References to properties and characteristics of a large electric furnace heat and two small induction furnace heats, made at another laboratory, are included.

The effect of aging and of hot-cold working on the rupture strength at 1200°F is presented, data on solution treated specimens of the six alloys having been reported previously. Previous work indicated that aging did not improve the rupture strength of titanium-boron strengthened austenitic alloys and this was substantiated by the present work, except in that the low boron - zero titanium (heat 201) showed some improvement in rupture strength on aging. Hot-cold working 20% at 1200°F greatly increased the rupture strength of all the alloys except the low boron-zero titanium heat(201) which was only slightly increased. An alteration in either the direction or degree of change of both the rupture strength and the hardness vs. boron content occurred at an aimed content of 0.03% boron.

A study was made of the precipitation reactions which occurred in the alloys and other microstructural factors of interest. General background precipitation on aging for 24 hours at 1500°F was more evident in the alloys containing titanium than in the straight boron alloys;

also a discontinuous grain boundary precipitate formed on aging. Some appreciable fraction of the added boron is tied up in a high melting point secondary phase since such a phase was present in the straight boron alloys, but not in the very low-boron zero-titanium heat (201). Lattice parameters did not change significantly on aging.

Chemical analyses were obtained for the six alloys, but they indicated some boron contents to be higher than would have been possible with 100% recovery of the added boron. The problems associated with the determination of chemical analyses are discussed and exemplified.

Future work will center around the preparation and examination of vacuum melted alloys. These materials should give more positive answers to such problems as the composition of various secondary phases, the true direction of lattice parameter changes due to alloying, and the influence on strength of dissolved boron and titanium rather than that produced when part of the boron or titanium are tied up as carbides, nitrides, or oxides.

INTRODUCTION

This report covers the progress made on the research work authorized under Contract No. AF 33(616)-173 (Expenditure Order No. R-463-8 BR-1) up to 31 July 1953.

Six modifications of a lean austenitic alloy containing varying amounts of boron and titanium were previously made and a report has been submitted covering the properties of these modifications in two solution treated conditions. The present report covers the continuation of the work on these six heats in an aged condition, 24 hours at 1500°F subsequent to solution treatment, and as hot-cold worked 20% at 1200°F.

Complete chemical analyses are reported for the six heats, however it will be shown that the obtained boron analyses are not consistent with the actual boron additions to the melts. The following table will serve to orient the reader with respect to the analysis of materials under study, past and present.

Chemical Analysis

Heat No.	C	Mn	Si	S	P	Cr	Ni	Mo	W	Ti	B	Fe
A-5764*	0.069	1.43	0.58	0.011	0.014	12.5	16.2	2.42	0.60	0.58	0.027	Bal
D41	0.045	1.33	0.32			13.69	15.03	2.02	0.61	0.60	0	Bal
D42	0.60	1.25	0.33			13.20	15.03	2.04	0.64	0.51	(0.03) 2nd Anal - (0.097)	Bal
Aimed Analyses												
201										0	0.01	
202										0	0.10	
203										0.60	0.005	
204										0.60	0.10	
205										0	0.03	
206										1.5	0.03	

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* All heats were made in a laboratory induction furnace except heat A-5764 which

Where it is pertinent and of value to a clearer and more complete understanding of the materials under investigation, references will be made to previously reported data on heats A-5764, D41 and D42.

GENERAL PROCEDURE

Two broad phases of the problem of the influence of boron and titanium on the rupture strength of a lean austenitic alloy will be considered in this report. On is concerned with the disposition of the boron and titanium in the alloy; this would include a study of the compounds or phases present in solution treated and solution treated plus aged specimens, their mode of occurrence and composition, and the general problem of chemical composition. The second general phase of the work consists of a study of the mechanical properties of the materials as they are affected by the disposition of the alloying elements, overall chemical composition, and by lattice strains produced by hot-cold working.

Problems associated with the disposition of the alloying elements were approached from the standpoint of microstructures, variations in microstructures with heat treatment, lattice parameters, and chemical analyses. The mechanical properties which were measured to determine the effect of changing the disposition of the alloying elements were rupture strengths at 1200°F and room temperature hardness.

TEST MATERIALS

The materials used in the present work were the six titanium-boron

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was a large electric furnace heat.

alloys whose preparation has been described previously. They were 15-pound laboratory induction furnace heats. On the basis of experience obtained in the laboratory of a commercial producer, it was assumed that 30% of the added boron and 60% of the titanium would be retained in the poured ingot. The chemical analyses of these heats will be given in the results section.

Rolled bar stock from these ingots was given either a full or an incomplete solution treatment, 1 hour at 2150°F or 4 hours at 1900°F, respectively. Specimens from each of these treatments were given a subsequent age of 24 hours at 1500°F. Since it had previously been determined that aging did not improve the rupture strengths at 1200°F, this aging treatment was chosen with the idea in mind of producing an overaged structure which might permit an identification of precipitating constituents and thus an insight into the disposition of alloying elements in the solution treated condition, rather than with the idea of producing a stronger condition.

Another portion of stock was hot-cold worked 20% at 1200°F to determine the effect of varying titanium and boron contents on the susceptibility of the alloy to be improved by such working. Perhaps higher rupture strengths would have been obtained by rolling at 1000°F, but data previously presented on the electric furnace Heat A-5764 suggested that greater variability in strength and lower ductility might result from the lower rolling temperature.

RESULTS

Disposition of Alloying Elements

Chemical Analyses

Chemical analyses have been obtained for the six alloys under study; the compositions are listed in Table I.

The results are believed to have been carefully made by chemists who have had considerable experience with boron analyses. The presence of impossible results are evidence of the difficulties and uncertainties connected with the procedures for obtaining analyses for boron in the composition ranges of the six alloys.

Factors which can be proposed to account for the failure of some of the chemical analyses to fall within possible ranges are at best unsatisfactory. There were considerable "fines" among the chips which were machined for the analyses. As there are considerable quantities of hard secondary phases, which have been assumed to contain boron, in most of the modifications it is possible that the quantity of the "fines" used in the analyses could have varied widely and thus accounted for the wide range of per cent recoveries: 2.7% to 400%. Another factor to be considered is the carry-over of boron or boron compounds, on the inside of the melting crucible, from one heat to the next. This might explain the high recovery obtained for heat 203, since it was a low-boron heat following a high-boron heat. Similarly, heat 201 may have contained less boron than the aimed because of boron left behind in the crucible after melting, there being no counterbalancing of this effect by the previous heat since it contained no boron.

Metallography

Microstructures of the six heats in the aged condition are presented in Figures 1 through 6. The significance of the results obtained from them cannot be completely evaluated. A large part of the material which formed the excess phase stringers in alloys is a boron containing compound, since approximately the same amount and type of excess phase stringers appeared in both the titanium bearing and titanium free heats (Figures 2 and 4), except 201 which contains very little boron and was quite clean (Figure 1). Boron contents of over 0.03% resulted in a sharply increased amount of stringers. The titanium heats showed, in addition, scattered Ti N cubes (Figure 3). The Ti N cubes often exhibited a duplex structure, either by a division irregularly through the cubes or by the formation of a symmetrical outside darker shell (Figures 4 and 6).

Aging produced the formation of a relatively massive grain boundary precipitate which somewhat resembled the boron compound phase. This precipitate formed in all heats including the low boron - zero titanium heat 201 (Figures 1 and 6). The precipitate could be a boron carbide or nitride or an $M_{23}C_6$ type of carbide. Aging also produced a general background precipitate (Figures 3, 4 and 6) which appeared to be more prevalent in the titanium bearing heats.

It was stated in the last progress report, Progress Report No. 3, that no change in grain size, of more than one A.S.T.M. number, occurred by raising the solution treating temperature from 1900° to 2150°F. Since, as usually happens, the aging process sharpened the observable grain size, an exception should be made to the above statement. Heat number 203 showed a gain size change from A.S.T.M. No. 5-6 to A.S.T.M. No. 3-4 due to the raising of the solution temperature. This is quite in accordance with the general cleanliness of the structure.

The previous induction furnace heat D-42, containing 0.03%B (0.09%B) and 0.60% Ti, exhibited a microstructure quite similar to heats 202 or 204 (Figures 2 and 4). The electric furnace heat number A-5764, containing 0.027% B and 0.60% Ti was much cleaner than any of the other heats except 201; it did not show massive grain boundary precipitates on aging. It is undoubtedly true that cleaner heats and higher recoveries of reactive additions, such as boron and titanium, are obtainable in large electric furnace heats than is possible with small induction furnace melts.

Lattice parameter measurements were made on the aged materials and the values determined are given in TableII. Another determination of the precision of the computed lattice parameter values on these alloys was obtained. The results substantiated the previous reported precision of ± 0.0006 kx for lattice parameter measurements reported in the Third Progress Report. This method consisted of analyzing the x-ray films by statistical means in the manner proposed by Jette and Foote[1]. The precision obtained resulted in a probable error of 0.0002 kx and 95% fiduciary limits of ± 0.0006 kx.

The lattice parameters indicated generally that the removal from the matrix of the atoms precipitating out on aging either did not appreciably alter the lattice or that equivalent amounts of atoms, some of which would increase and some decrease thelattice spacing, were removed from solution. It is difficult to imagine how the former case could exist; the latter case, however, could be represented by the removal of substitutional boron and substitutional titanium on aging (Figure 7).

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[1] Jette, E.R. and Foote, F. J. Chem. Phys. 3, 605 (1935).

Mechanical Properties

Rupture properties of the six modifications were determined at 1200°F on specimens which had been aged 24 hours at 1500°F and on others which had been hot-cold worked 20% at 1200°F; the results are given in Table III. Brinell hardness measurements were also made on these conditions of the six heats (Figure 8).

The variations in the 100-hour rupture strength with boron content for the (1) solution treated, (2) aged and (3) hot-cold worked conditions are represented in Figure 9. This latter figure shows quite clearly that:

1. Aging generally reduced the rupture strength.

2. Aging slightly increased the strength only of the low boron - zero titanium heat 201.

3. Aging reduced the strength of the titanium heats more than for the straight boron heats.

4. Hot-cold working greatly increased the rupture strength of most of the modifications.

5. Hot-cold working increased the rupture strength of the low boron heats very little unless they contained titanium, and then the increase was very pronounced.

6. The rupture strengths of the titanium bearing heats tended to reach a maximum at 0.03% boron, while the straight boron heats tended to increase in strength quite rapidly up to 0.03% boron and to keep on increasing in strength, but at a lower rate for higher boron contents. This trend was also apparent for the hardness variations.

The following table presents a comparison of selected 100-hour rupture strengths at 1200°F.

Heat No.	Condition	Rupture Strength	Elongation (%)	Grain Size
A-5764	2150°F - 1 hr	40,000	38	3
204	2150°F - 1 hr	42,000	38	5
206	2150°F - 1 hr	44,000	52	5
D-42	2150°F - 1 hr	44,000	33	5
A-5764	2150°F - 1 hr + 20% HCW at 1200°F	56,000	3	
204	2150°F - 1 hr + 20% HCW at 1200°F	56,000	15	
206	2150°F - 1 hr + 20% HCW at 1200°F	63,000	12	
204	2150°F - 1 hr + 24 hrs at 1500°F	32,500	46	
206	2150°F - 1 hr + 24 hrs at 1500°F	44,500	40	

Figures 10 and 11 are log-log plots of the rupture data of the six alloys as (1) solution treated, (2) aged and (3) hot-cold worked, and Figure 12 is a summary plot which presents very graphically the effect of the various treatments on the 100-hour rupture strength

Hardness of the different materials, as a function of boron content, is plotted in Figure 8. Three conditions are represented: solution treated, aged and hot-cold worked. Aging produced only a minor increase in hardness while hot-cold working raised the Brinell hardness values from about 140 BHN to in the vicinity of 240 BHN.

FUTURE WORK

Vacuum melted heats will be fabricated and examined to determine individually the influence of carbon, nitrogen and oxygen on the effect of boron. Precipitation reactions, effect of working on the rupture strength, and lattice parameters will be followed.

Work will also be completed on the effect of rolling temperature on the rupture strength and ductility of the electric furnace heat A-5764.

CONCLUSIONS

The disposition of the boron and titanium, i.e., presence in solution or in precipitates and in different kinds of precipitates, has been difficult to follow. It has been indicated that much of the boron in excess of approximately 0.03%, or less, is probably tied up in inert secondary phases. Aging produced a background precipitate and a grain boundary precipitate, the former being perhaps more evident in the titanium bearing alloys. Aging did not appreciably change the lattice parameters.

The value of chemical analyses for boron on materials containing appreciable quantities of the boron in compounds which are effectively inert to solution treatments is questionable. This conclusion resulted from the high recoveries of boron indicated by chemical analyses on materials containing considerable quantities of boron in metallurgically inert compounds.

The presence of titanium in the alloy was effective in producing higher 100-hour rupture strengths, either as solution treated or hot-cold worked, than the straight boron modifications. The 1.5% Ti alloy possessed the highest hot-cold worked rupture strength.

The 100-hour rupture strength of hot-cold worked titanium bearing alloys was much less affected by boron content than was the strength of the straight boron materials. Thus the response to hot-cold work, as measured by rupture strengths, of the straight boron alloys was very marked. This is particularly noteworthy when one considers the small changes in hardness with boron content of the hot-cold worked condition. It might be concluded that the working is responsible for a precipitation reaction similar to strain aging.

The conclusions previously reached, that aging was not beneficial to the rupture strength, has been substantiated, except in that the strength of the low boron - zero titanium alloy was slightly improved.

TABLE I

Chemical Analyses of Six Modifications of a Boron-Titanium Strengthened Austenitic Steel

Heat No.	C	Mn	Si	Cr	Ni	Mo	W	Al	N_2	B% Aim	B% Add	B% Anal 1	B% Rec Anal 1	B% Anal 2	B% Rec Anal 2	Ti% Aim	Ti% Anal
201T*	0.065								0.036	0.01	0.033	0.0008	2.7			0	
202T	0.057								0.029	0.10	0.33	0.163	49.0	0.162	49.0	0	
202B*	0.062								0.028	0.10	0.33	0.160	49.0	0.162	49.0	0	
203T	0.045								0.024	0.005	0.017	0.068	400.			0.60	0.70
204T	0.044	1.57	0.63	13.41	15.20	1.90	0.49	0.03	0.026	0.10	0.33	0.267	81.0	0.238	72.0	0.60	0.58
204B	0.036								0.024	0.10	0.33	0.341	102.0	0.238	72.0	0.60	0.56
205T	0.055								0.040	0.03	0.10	0.224	224.0			0	0
206T	0.046								0.034	0.03	0.10	0.236	236.0			1.5	1.73

*T - top of ingot and sample materials had been solution treated at 2150°F.
*B - bottom of ingot and sample material had been solution treated at 1900°F.

Blank spaces indicate analyses not made.

NOTE: B% Rec, Anal 1, represents the per cent recovery of boron based on the first analyses, likewise for the second analysis.

TABLE II

Lattice Parameters of Boron-Titanium Austenitic Alloys

Heat No.	Aimed B%	Aimed Ti%	Analyses B	Analyses Ti	Analyses N	Analyses C	Heat Treatment	Lattice Parameter (kx)
201	0.01	0	0.0008	0	0.036	0.065	S.T. 2150°F 1 hr W.Q.	3.5871
201							S.T. 2150°F 1 hr W.Q. + Age 24 hrs at 1500°F	3.5869
201							S.T. 1900°F 4 hrs W.Q.	3.5857
201							S.T. 1900°F 4 hrs W.Q. + Age 24 hrs at 1500°F	3.5848
202	0.1	0	0.163^1	0	0.029	0.057	S.T. 2150°F 1 hr W.Q.	3.5836
202			0.341^2				S.T. 2150°F 1 hr W.Q. + Age 24 hrs at 1500°F	3.5841
202							S.T. 1900°F 4 hrs W.Q.	3.5840
202							S.T. 1900°F 4 hrs W.Q. + Age 24 hrs at 1500°F	3.5833
203	0.005	0.6	0.068	0.70	0.024	0.045	S.T. 2150°F 1 hr W.Q.	3.5838
203							S.T. 2150°F 1 hr W.Q. + Age 24 hrs at 1500°F	3.5850
203							S.T. 1900°F 4 hrs W.Q.	3.5863
							S.T. 1900°F 4 hrs W.Q. + Age 24 hrs at 1500°F	3.5851
204	0.10	0.6	0.160^2	0.58	0.026	0.044	S.T. 2150°F 1 hr W.Q.	3.5833
204							S.T. 2150°F 1 hr W.Q. + Age 24 hrs at 1500°F	3.5822
204							S.T. 1900°F 4 hrs W.Q.	3.5817
204							S.T. 1900°F 4 hrs W.Q. + Age 24 hrs at 1500°F	3.5824

TABLE II, Continued

Heat No.	Aimed		Analyses				Heat Treatment	Lattice Parameter(kx)
	B%	Ti%	B	Ti	N	C		
205	0.03	0	0.224	0	0.040	0.055	S.T. 2150°F 1 hr W.Q.	3.5861
205							S.T. 2150°F 1 hr W.Q. + Age 24 hrs at 1500°F	3.5856
205							S.T. 1900°F 4 hrs W.Q.	3.5849
205							S.T. 1900°F 4 hrs W.Q. + Age 24 hrs at 1500°F	3.5848
206	0.03	1.5	0.236	1.73	0.034	0.046	S.T. 2150°F 1 hr W.Q.	3.5898
206							S.T. 2150°F 1 hr W.Q. + Age 24 hrs at 1500°F	3.5890
206							S.T. 1900°F 4 hrs W.Q.	3.5890
206							S.T. 1900°F W.Q. + Age 24 hrs at 1500°F	3.5897

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[1] Top part of ingot

[2] Bottom part of ingot

TABLE III

Rupture Test Data from Tests at 1200°F for Six Induction Heats 201 - 206

with Varying Boron and Titanium Contents

Heat Number and Heat Treatment *	Stress (psi)	Rupture Time (hours)	Elongation (% in 1 in.)	Reduction of Area (%)	Estimated 100-Hour Rupture Strength (psi)	Estimated 100-Hour Rupture Elongation (%)
201 - S4	24,000	130.4	20.8	15	25,000	20
	27,000	54.8	20	20		
201 - S4A	25,000	127.3	47.6	45	26,000	50
	28,000	60.1	62	47		
201 - S4R	32,000	53.6	3.85	8	26,000	9
	40,000	16		10		
201 - S1	21,000	227.4	19	18.5	23,000	19
	25,000	49.5	19	12		
201 - S1A	22,000	390.9	46	41	26,000	50
	30,000	28.3	55	44		
201 - S1R	25,000	334.8	6.8	6.5	28,500	6
	38,000	7.0	3.8	8		
202 - S4	35,000	341	43	65	38,000	41
	41,000	18.1	40	38		
202 - S4A	27,000	1129.7	--	--	33,000	45
	35,000	49.8	53	56		
202 - S4R	48,000	257.7	15.4	55	49,500	21
	53,000	3.7	33	45		
202 - S1	33,000	427	42	67	38,000	37
	40,000	56.4	36	46		

* See code at end of table.

TABLE III, Continued

Heat Number and Heat Treatment	Stress (psi)	Rupture Time (hours)	Elongation (% in 1 in.)	Reduction of Area (%)	Estimated 100-Hour Rupture Strength (psi)	Estimated 100-Hour Rupture Elongation (%)
202 - S1A	29,000	1021	--	--	33,500	40
	35,000	56.0	45	57		
202 - S1R	50,000	487.3	14	49	--	--
203 - S4	31,500	139.7	49	65	33,000	50
	35,000	65.0	51	67		
203 - S4A	25,000	388.1	62	61.5	28,000	68
	33,000	14	80	72		
203 - S4R	46,000	86.2	15	57	45,000	13
	50,000	29.4	30.4	64		
203 - S1	30,000	769	40	45	36,000	60
	40,000	33.4	65	68		
203 - S1A	26,000	257.5	73.8	68	29,000	60
	35,000	16.9	46.6	57		
203 - S1R	49,000	349.2	25.5	37	53,000	19
	55,000	66.3	17	54		
204 - S4	35,000	227	--	--	39,000	--
	40,000	69.8	43.6	50		
204 - S4A	30,000	326	51.5	63	33,000	44
	36,000	38.5	38	59		
204 - S4R	52,000	241.1	16	49	54,000	15
	55,000	92.3	14.5	50		
204 - S1	40,000	139.9	33	64	42,000	38
	45,000	68.0	42	51		

TABLE III, Continued

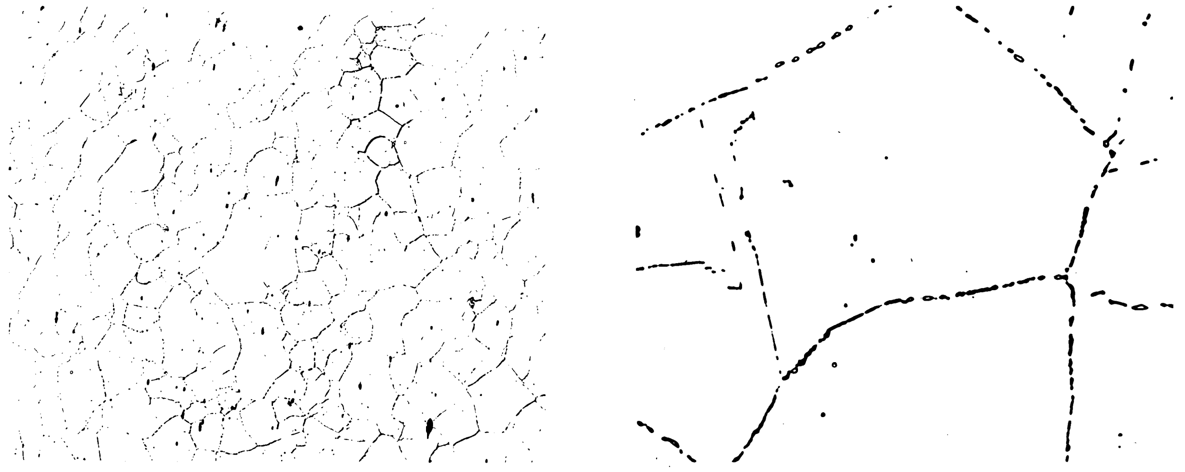
Heat Number and Heat Treatment	Stress (psi)	Rupture Time (hours)	Elongation (% in 1 in.)	Reduction of Area (%)	Estimated 100-Hour Rupture Strength (psi)	Estimated 100-Hour Rupture Elongation (%)
204 - S1A	30,000	343.4	45.6	64	32,500	46
	40,000	4.1	46.6	57		
204 - S1R	55,000	222	12.8	48	56,000	15
	60,000	6.1	15.7	49		
205 - S4	28,000	233	49	45	30,000	38
	32,000	54.9	32	37		
205 - S4A	26,000	434.8	58	63	28,500	59
	30,000	48.1	59	59		
205 - S4R	36,000	391.7	24.5	34	39,000	20
	45,000	12.9	18	28		
205 - S1	35,000	58.2	33	32	33,000	31
	40,000	13.5	35	29		
205 - S1A	26,000	260.1	54	53	28,500	53
	33,000	22	52.4	55		
205 - S1R	44,000	69	5.6	14	42,500	3
	50,000	17.6	12.6	12		
206 - S4	37,000	330	35	36	39,000	47
	45,000	3.4	52	61		
206 - S4A	28,000	892.5	--	--	33,000	--
	40,000	10.1	59	60		
206 - S4R	58,000	319.7	7.9	15	59,500	10
	62,000	12.3	21.6	44		

TABLE III, Concluded

Heat Number and Heat Treatment	Stress (psi)	Rupture Time (hours)	Elongation (% in 1 in.)	Reduction of Area (%)	Estimated 100-Hour Rupture Strength (psi)	Estimated 100-Hour Rupture Elongation (%)
206 - S1	40,000	862.5	23.6	23	44,000	52
	50,000	6.3	56.7	55		
206 - S1A	43,000	278.2	21	25	44,500	40
	47,000	9.5	70	57		
206 - S1R	60,000	656.2	6.9	9	63,000	12
	68,000	4.2	21.5	53		

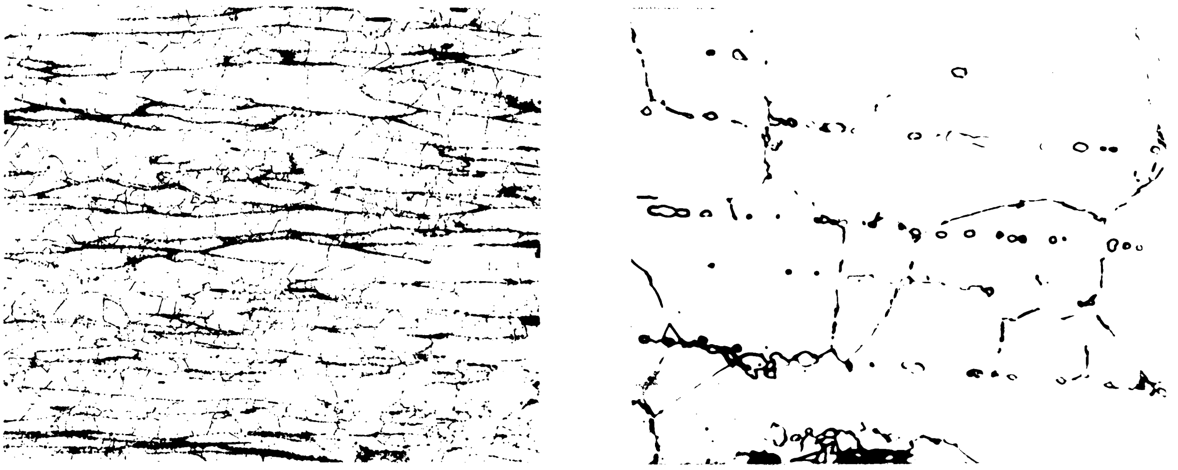
Code for Heat Treatments:

S4 - S.T. 1900°F 4 hrs W.Q.
S4A - S.T. 1900°F 4 hrs W.Q. + 24 hrs at 1500°F
S4R - S.T. 1900°F 4 hrs W.Q. + 20% Red. at 1200°F
S1 - S.T. 2150°F 1 hr W.Q.
S1A - S.T. 2150°F 1 hr W.Q. + 24 hrs at 1500°F
S1R - S.T. 2150°F 1 hr W.Q. + 20% Red. at 1200°F



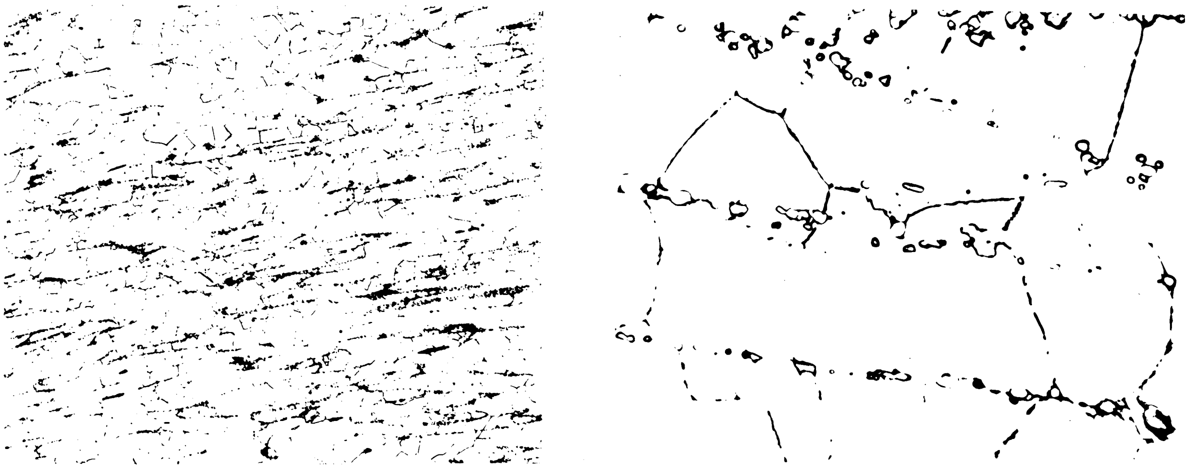
X100D X1000D

Figure 1 - Microstructure of Heat 201 Solution Treated 4 Hours at 1900°F Plus Aged 24 Hours at 1500°F, Aim Composition 0.01% B, 0% Ti.



X100D X1000D

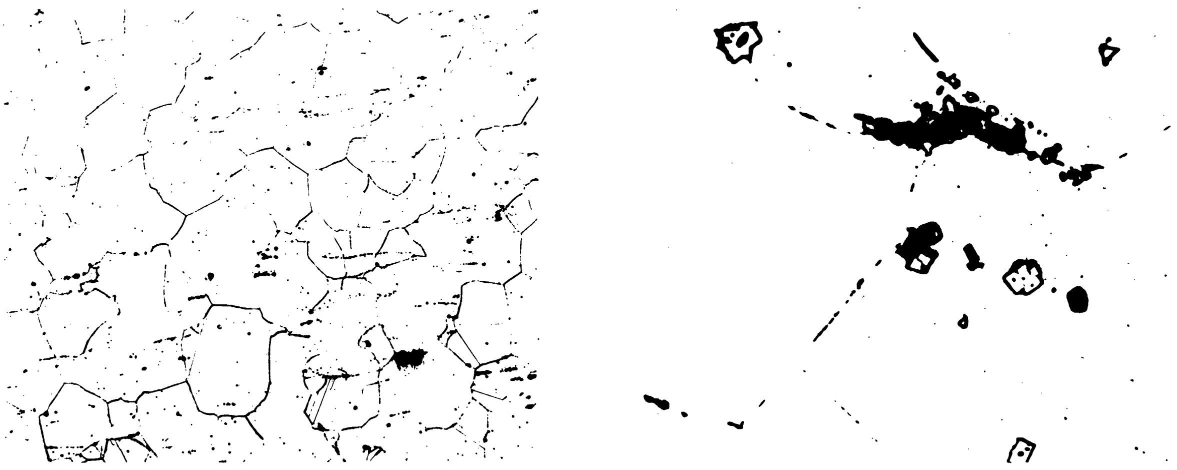
(a) Solution treated 4 hours at 1900°F, water quenched.



X100D X1000D

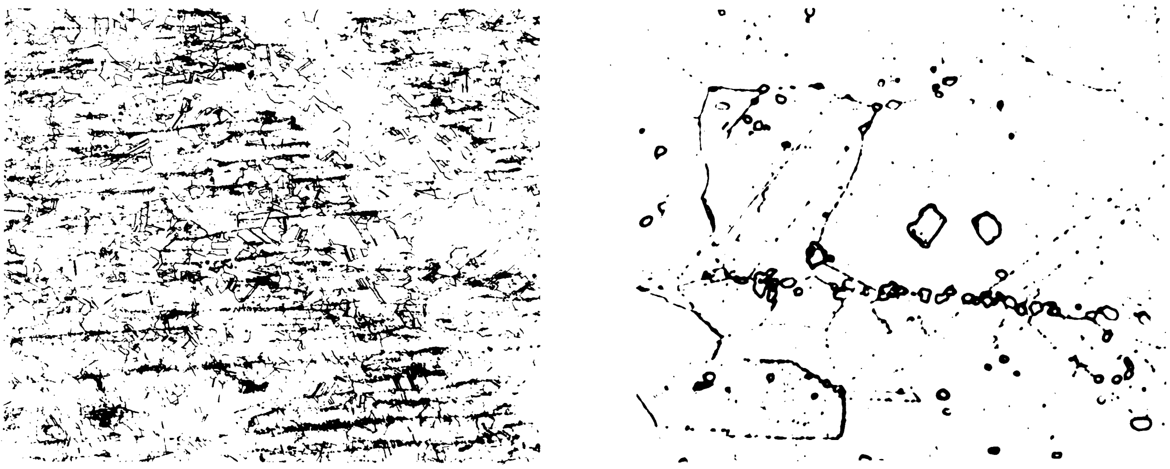
(b) Solution treated 1 hour at 2150°F, water quenched.

Figure 2 - Microstructures of Heat 202 Aged 24 Hours at 1500°F, Aim Composition 0.10% B, 0% Ti.



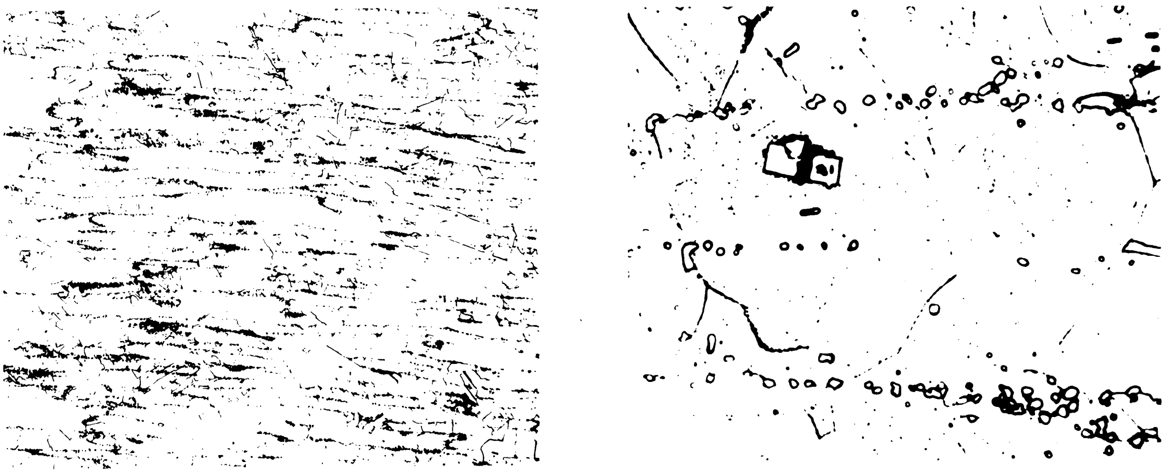
X100D X1000D

Figure 3 - Microstructure of Heat 203 Solution Treated 1 Hour at 2150°F Plus Aged 24 Hours at 1500°F, Aim Composition 0.005% B, 0.60% Ti.



X100D X1000D

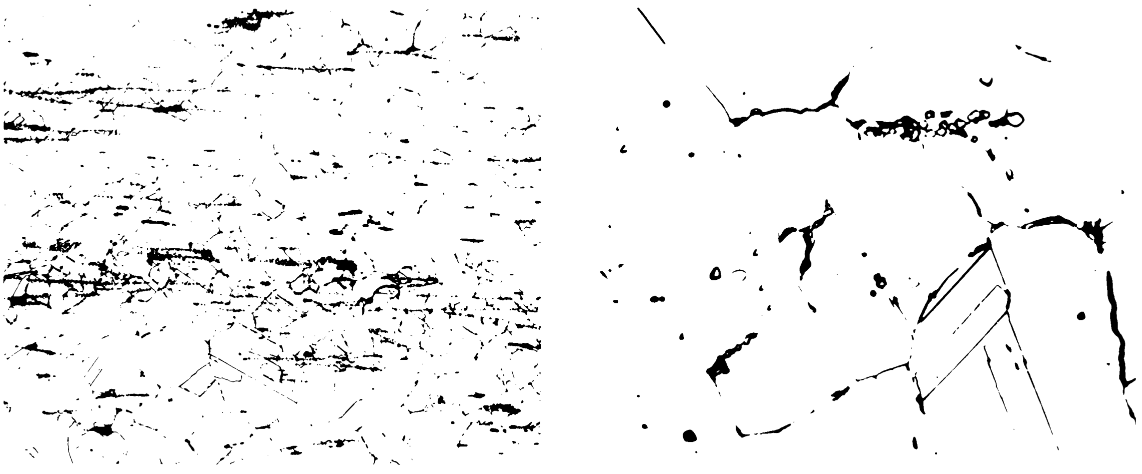
(a) Solution treated 4 hours at 1900°F, water quenched.



X100D X1000D

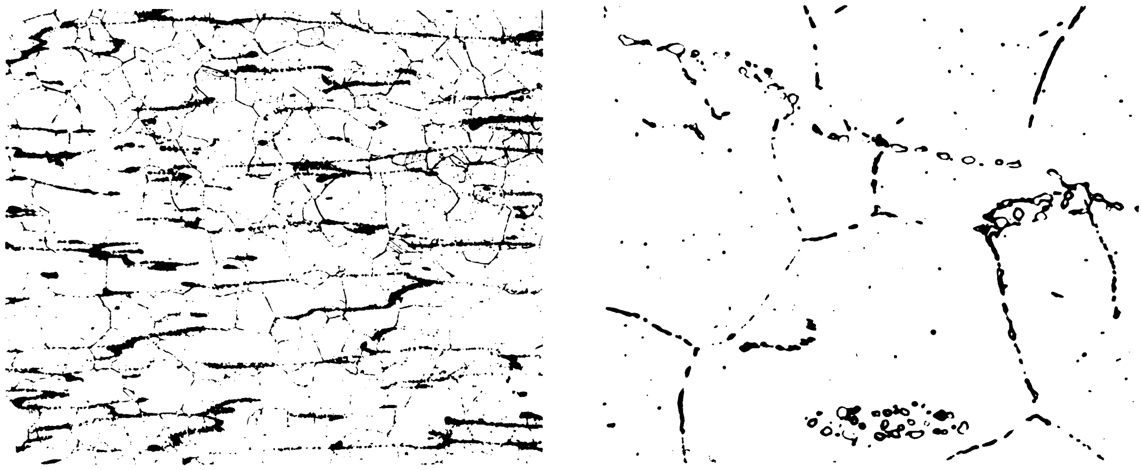
(b) Solution treated 1 hour at 2150°F, water quenched.

Figure 4 - Microstructures of Heat 204 Aged 24 Hours at 1500°F, Aim Composition 0.10% B, 0.60% Ti.



X100D X1000D

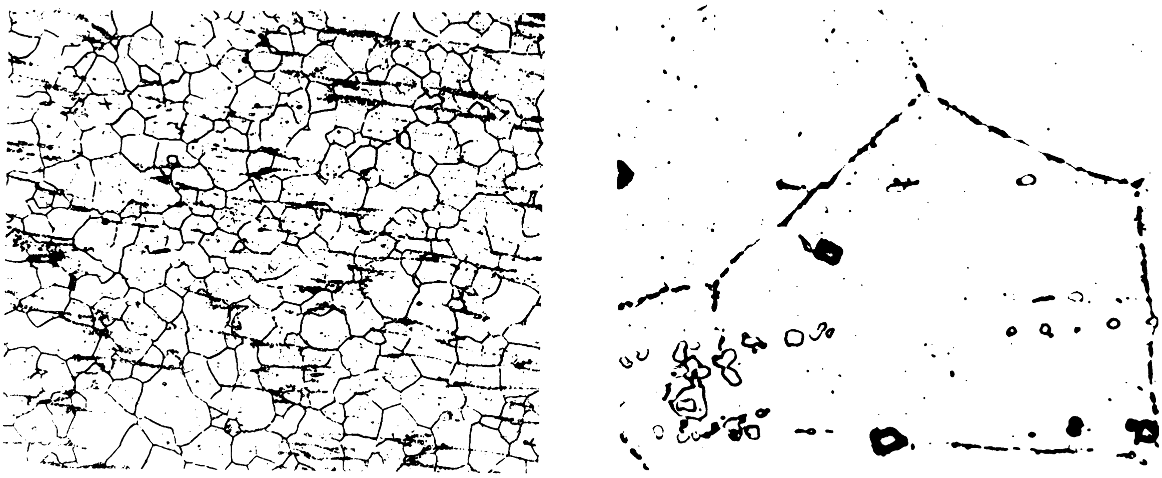
(a) Solution treated 4 hours at 1900°F, water quenched.



X100D X1000D

(b) Solution treated 1 hour at 2150°F, water quenched.

Figure 5 - Microstructures of Heat 205 Aged 24 Hours at 1500°F, Aim Composition 0.03% B, 0% Ti.



X100D X1000D

Figure 6 - Microstructure of Heat 206 Solution Treated 1 Hour at 2150°F Plus Aged 24 Hours at 1500°F, Aim Composition 0.03% B, 1.5% Ti.

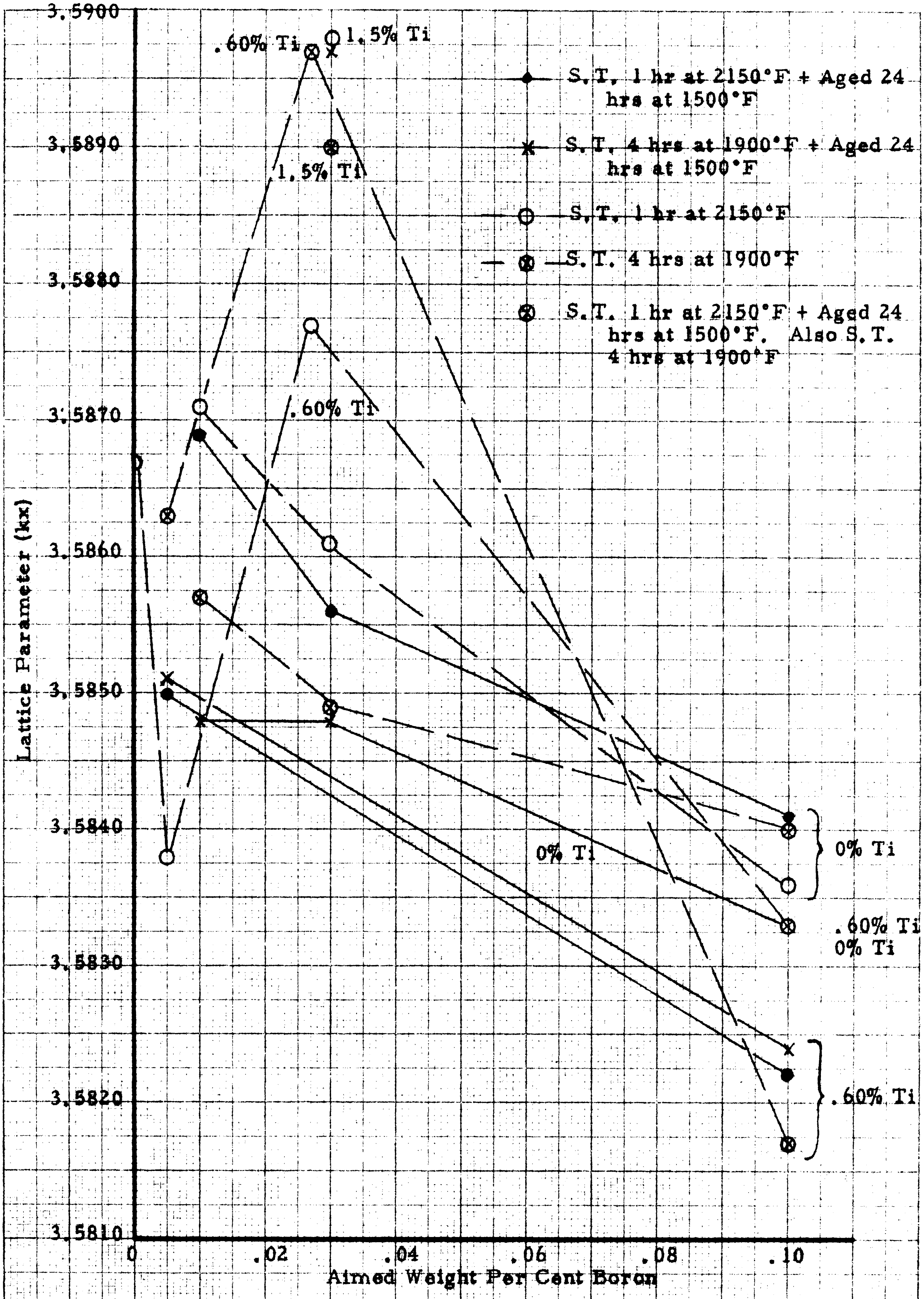


Figure 7. - Effect of Boron Content on the Lattice Parameter of a Lean Austenitic Alloy in the Solution Treated and Solution Treated Plus Aged 24 Hours at 1500°F Conditions, at Constant Titanium Percentages.

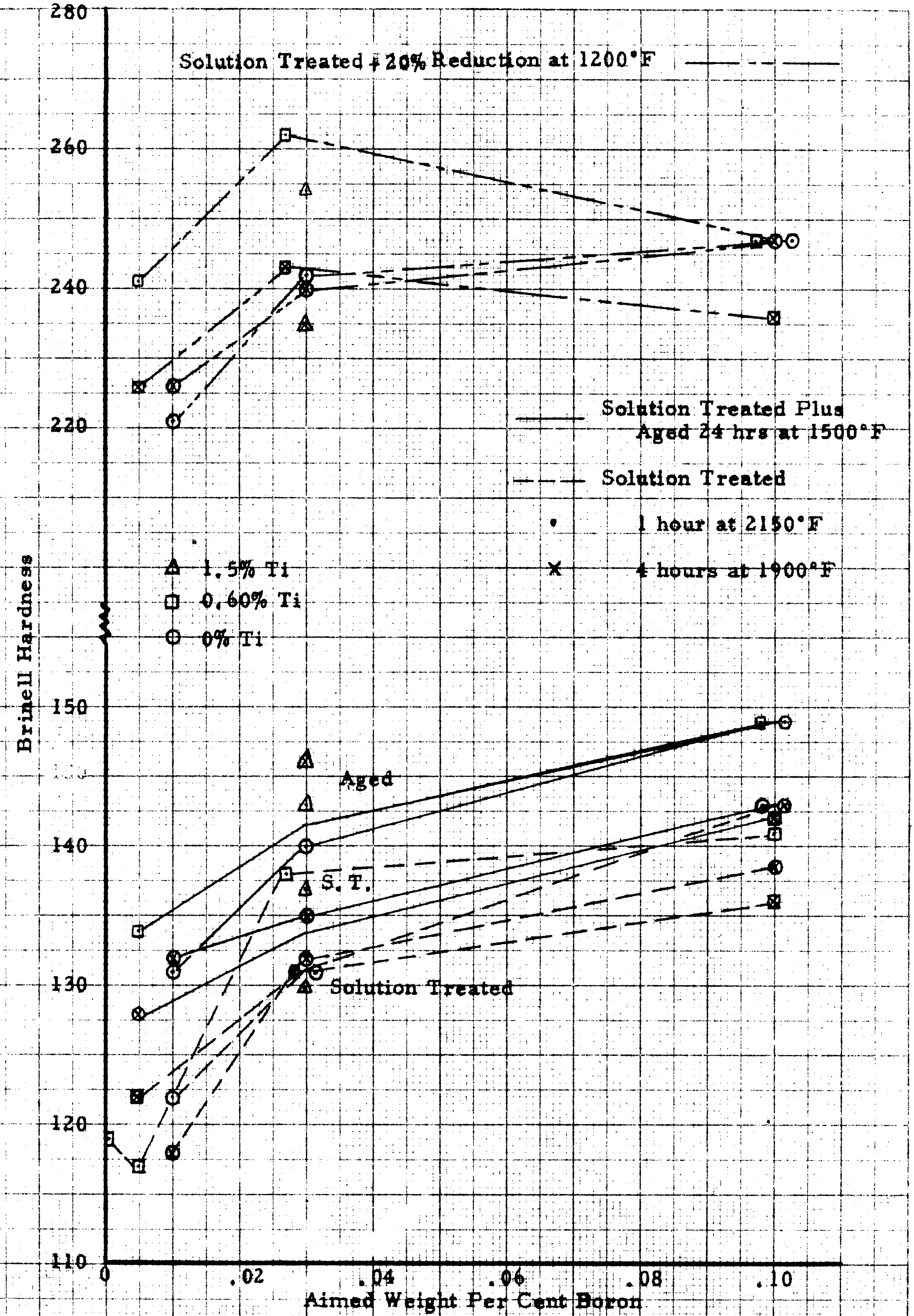


Figure 8. - Effect of Increasing Boron Content on the Brinell Hardness of an Austenitic Base Alloy in the Solution Treated, Aged and Hot-Cold Worked Condition at Constant Titanium Percentages.

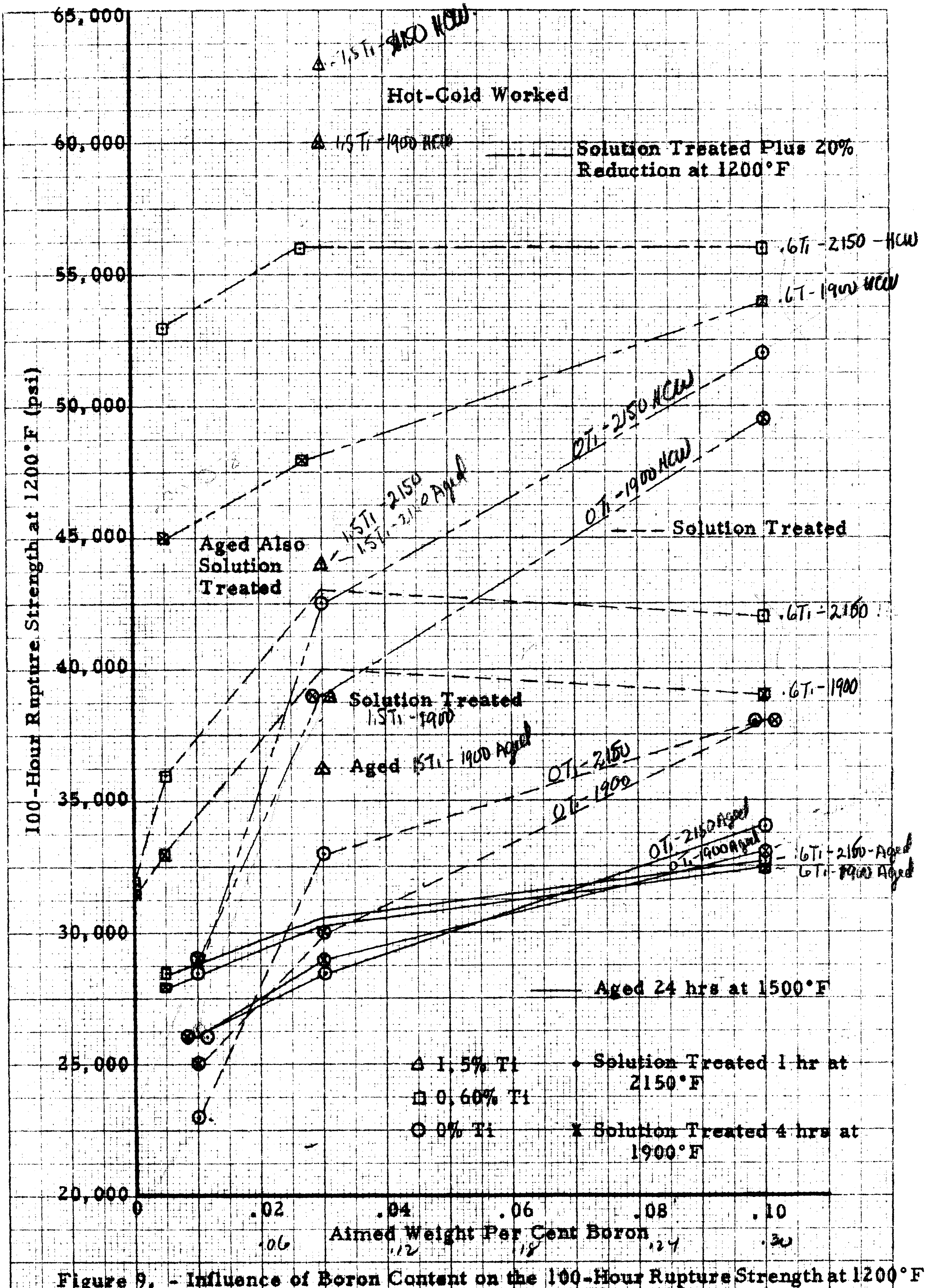
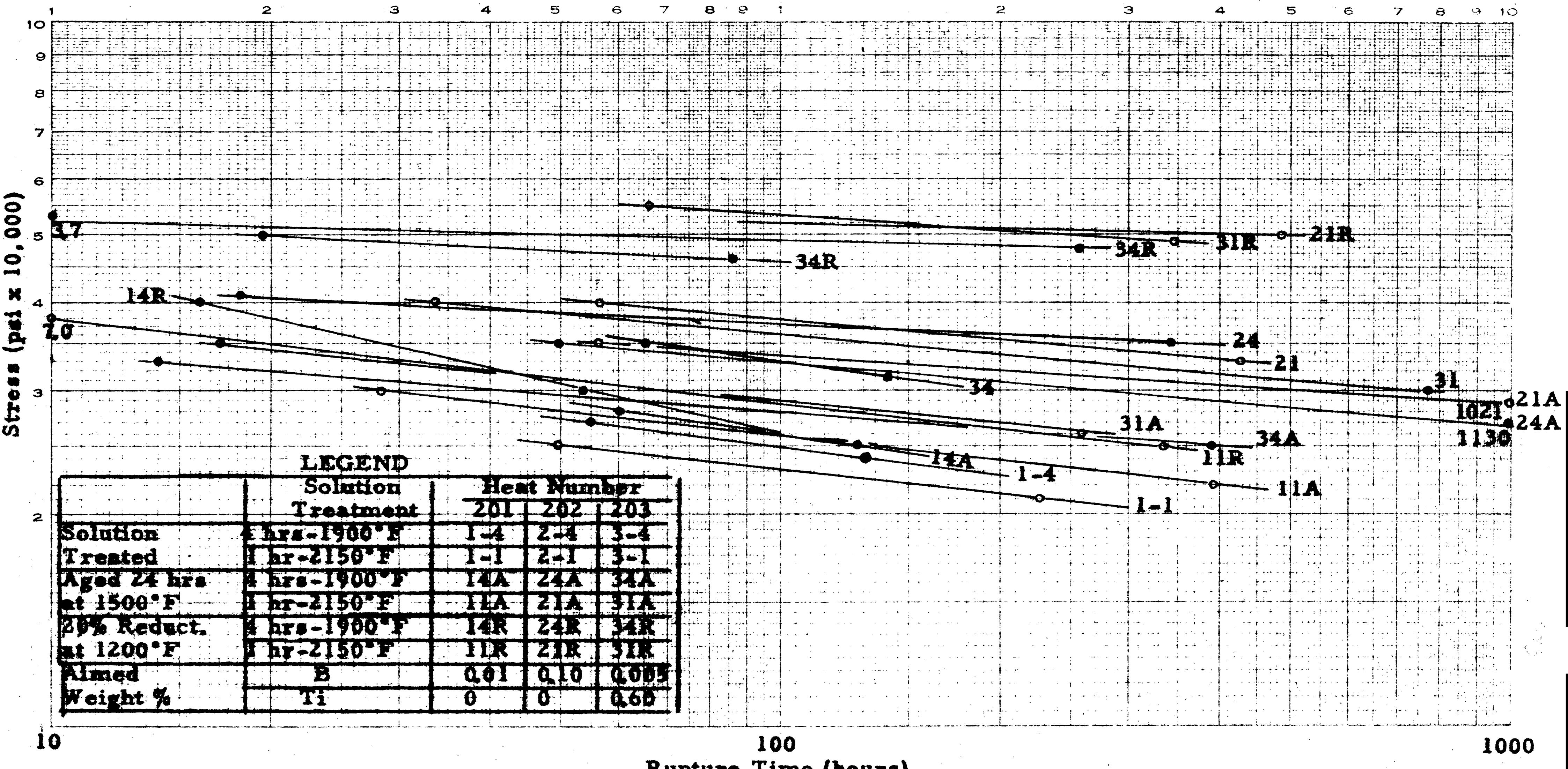
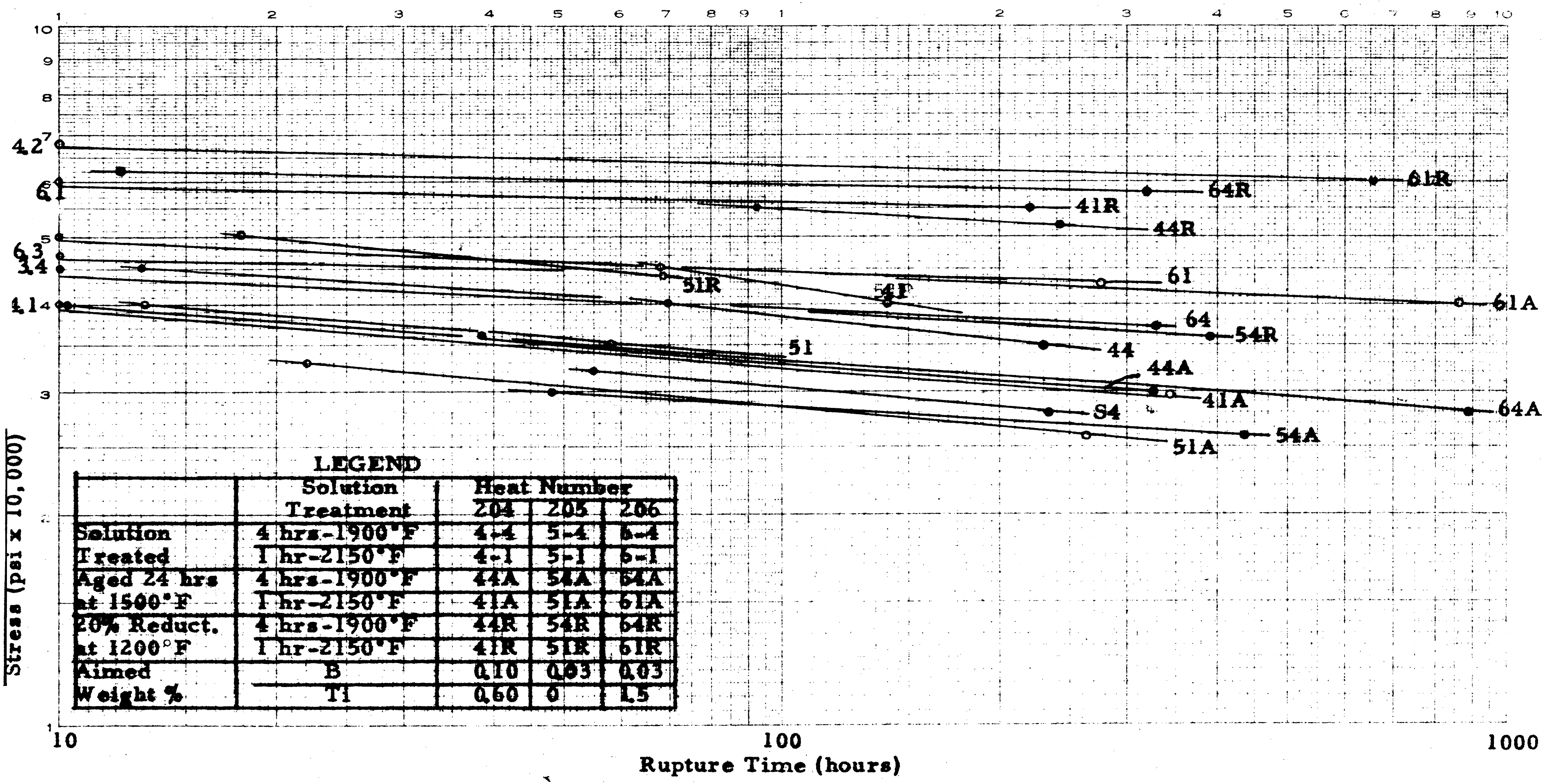


Figure 9. - Influence of Boron Content on the 100-Hour Rupture Strength at 1200°F for a Lean Austenitic Base Alloy at Constant Titanium Percentage in the Solution Treated, Aged and Hot-Cold Worked Conditions.



	Solution Treatment	Heat Number 201	202	203
Solution Treated	4 hrs-1900°F	1-4	2-4	3-4
	1 hr-2150°F	1-1	2-1	3-1
Aged 24 hrs at 1500°F	4 hrs-1900°F	14A	24A	34A
	1 hr-2150°F	11A	21A	31A
20% Reduct. at 1200°F	4 hrs-1900°F	14R	24R	34R
	1 hr-2150°F	11R	21R	31R
Aimed Weight %	B	0.01	0.10	0.005
	Ti	0	0	0.60

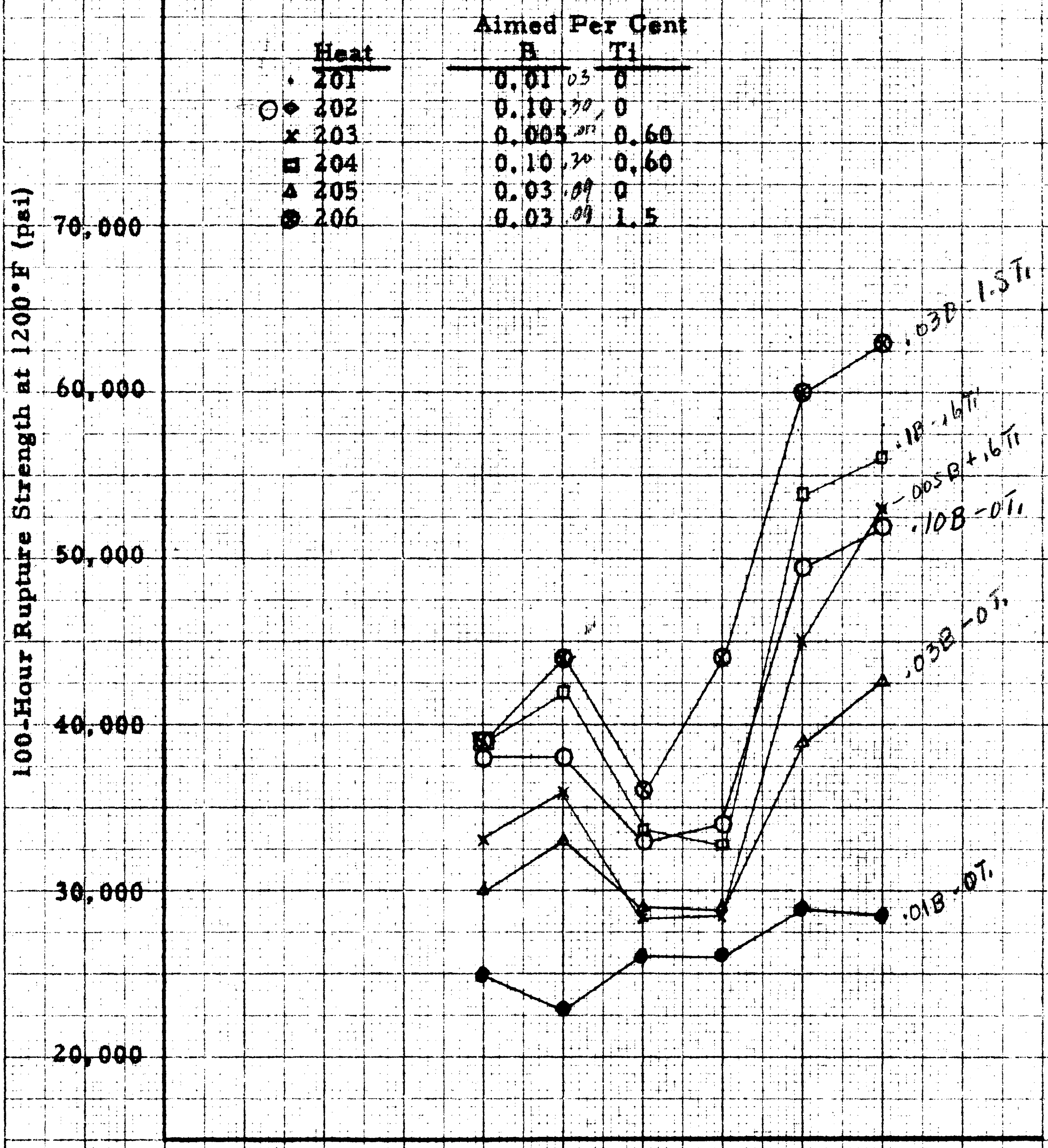
Figure 10. - Comparative Stress-Rupture Properties at 1200°F for Induction Heats 201, 202 and 203 in the Solution Treated, Aged and Hot-Cold Worked Conditions.



LEGEND

	Solution Treatment	Heat Number		
		204	205	206
Solution Treated	4 hrs-1900°F	4-4	5-4	6-4
	1 hr-2150°F	4-1	5-1	6-1
Aged 24 hrs at 1500°F	4 hrs-1900°F	44A	54A	64A
	1 hr-2150°F	41A	51A	61A
20% Reduct. at 1200°F	4 hrs-1900°F	44R	54R	64R
	1 hr-2150°F	41R	51R	61R
Aimed Weight %	B	0.10	0.03	0.03
	Ti	0.60	0	1.5

Figure 11. - Comparative Stress-Rupture Properties at 1200°F for Induction Heats 204, 205 and 206 in the Solution Treated, Aged and Hot-Cold Worked Conditions.



S. T. (°F)	1900	2150	1900	2150	1900	2150
S. Time (hrs)	4	1	4	1	4	1
Aging Temperature	-	-	1500	1500	-	-
Aging Time (hrs)	-	-	24	24	-	-
Hot-Cold Work						
Temperature	-	-	-	-	1200	1200
Reduction (%)	-	-	-	-	20	20

Figure 12. - 100-Hour Rupture Strengths of Six Ti-B Austenitic Steels at 1200°F in Different Conditions of Heat Treatment and Hot-Cold Working.